ARMORED FORCE MEDICAL RESEARCH LABORATORY
Fort Knox, Kentucky

Project No. 2-6
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Partial Report

WATER AND SALT REQUIREMENTS FOR DESERT OPERATIONS

1. PROJECT: Water and Salt Requirements for Desert Operations.

a. Authority: Letter Commanding General, Headquarters, Armored Force, Fort Knox, Kentucky, 400.112/6 GNOHD, dated September 24, 1942.

b. Purpose: To determine the water and salt needs of Armored Force Personnel for desert operations.

2. DISCUSSION:

a. Methods: Water balance studies and chloride excretions were ~~followed~~ on 52 subjects; 37 men from a light-tank company during maneuvers, 10 medium-tank crewmen during instructional periods and 4 members of the laboratory staff. All liquid intake and urinary output was measured and recorded - evaporative water loss determined by weighing. Details of procedure and analysis of results are given in the Appendix.

b. Ambient Temperature: Throughout these investigations temperatures in the desert were rather mild (Chart 1, Appendix). Requirements indicated by these studies must therefore be considered as minimum requirements.

3. CONCLUSIONS:

~~a.~~ For the period of ~~our~~ this study a drinking water ration of 2 gallons per day was required by the majority of men.

~~b.~~ One gallon per day even under mild temperature conditions was inadequate and caused lowering of efficiency.

~~c.~~ All tank crew members required about the same amount of water.

~~d.~~ Water requirements greater than those noted ~~will~~ be encountered at higher temperatures and with greater activity.

~~e.~~ Salt balance was maintained in all subjects without extra salt. Conditions were not severe, however, and the men were well acclimatized.

STATEMENT NO. 1

. Salt tablets were unsatisfactory in a sufficient number of instances to make advisable other means of increasing salt intake.

f. No advantage in physical well-being or enconomy of water was gained by limiting water drinking to meal time only.

4. RECOMMENDATIONS:

a. Not less than 2 gallons of drinking water per day should be provided for each man even under mild desert conditions (95° to 105°F).

b. No salt in excess of that present in modified field ration or K-2 Ration is needed for mild desert conditions (95° to 105°F).

c. When extra salt is needed it should be provided by addition of salt to the food and/or water.

d. Personnel should not be advised to drink only at meal time but in small amounts when thirsty.

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Project No. 2-6 APPENDIX

(To Partial Report)

WATER AND SALT REQUIREMENTS FOR DESERT OPERATION

1. GENERAL DISCUSSION: The energy used by the human organism to maintain the vital processes and to do work is finally dissipated from the body in large part as heat. At ordinary temperatures this escapes chiefly by convection and by radiation to cooler surfaces. Generally conduction accounts for only a small percentage of the total heat loss, while evaporation other than sweating accounts for about 25% of the total heat dissipated. The latter, known as insensible perspiration, is lost with the expired air and by diffusion through the skin.

When the air temperature rises to the skin temperature loss of heat by convection is no longer possible, and as the air temperature rises above skin temperature the body actually gains heat from the air. Similarly when one is exposed to a hot sun or is surrounded by walls warmer than the skin, radiant heat is gained by the body rather than lost. In this situation, when the usual means of heat loss fail, sweating occurs, and heat is dissipated wholly by evaporative cooling. Only in this way can heat balance be maintained when the usual pathways are inadequate, or act as a source of extra heat gain. The cooling effected by the evaporation of water owes its high efficiency to its large latent heat of vaporization. This has the value of 580 kilogram calories per liter of water evaporated at room temperature. Under conditions of dry heat where sweat evaporates without running off, the sweating mechanism is practically completely efficient and the entire 580 large calories are extracted from the surface where evaporation occurs for every liter of water vaporized. As soon as heat balance is established, the rate of sweat secretion falls off to a rate adequate to maintain the body temperature at close to its normal level.

In evaluating the water needs for a given situation the losses other than sweat must be considered. The losses in the feces are ordinarily low and relatively constant, amounting to about 80 to 100 ml. per day. The water lost in the urine will depend on the water intake when this is more than adequate to keep the body normally hydrated; however, even in severe water restri tion with accompanying dehydration, urine output will rarely fall below 20 ml. per hour. This represents the minimum level of excretion adequate for the normal excretory functions of the kidneys. Thus about 600 ml. per day are essential, and unavailable for cooling purposes. The water lost by insensible perspiration effectively cools the body as it evaporates; no distinction need be drawn between it and true sweat secretion from the cooling standpoint. The former is, however, lost without salt and does not place the drain on the salt reserve of the body that sweat does.

APPENDIX (cont'd)

At the time of the present study in the desert the situation was generally such that heat was being gained from the environment during only part of the day, during the remainder heat balance could be maintained without evaporative cooling. To illustrate, one may analyze the average net fluid loss value found for Group 2a (See Table I). These men were in energy balance at about 3700 calories (the caloric value of K-2 Ration) per day. If we assume that for 16 hours about 100 calories per hour (a nearly basal rate) were expended, we are left with 3700 - 1600 or 2100 calories arising from metabolic processes during the eight working hours. To estimate the total heat dissipated, one should add to the net fluid loss of 4.518 liters about 0.5 liters (approximating the water contained in and produced by oxidation of food); this gives a total of 5.018 liters for the total evaporative loss for 24 hours. During the 16 night hours, water would be lost by insensible perspiration; the water loss by this route would be equivalent to about 25% of the energy expended during that period. Thus, $0.25 \times 1600 = 400$ calories; the water equivalent would be 400/580 or 0.690 liters. This taken from 5.018 liters gives 4.328 liters, the evaporative loss for the 8 hour day period. 4.328 liters in evaporation would dissipate 4.328×580 or 2510 calories. Since only 2100 calories were produced by metabolism during that interval, the difference between 2510 and 2100, or 410 calories, represents the heat gained by convection and radiation for the 8 hour interval. This rough estimate would suggest a heat gain from the environment of 50 calories per hour.

It is well known that during the process of acclimatization the rate of sweating will increase. In one of our laboratory subjects the rate of sweat formation for a standard one hour walk in the sun on the second day in the desert was 700 ml. and rose to 1200 ml. for the same activity on the fourth day. Heat accumulation was distinctly lower in the second instance as shown by a smaller rise in rectal temperature. By such an improvement in ability to dissipate heat, acclimatization improves one's tolerance for high temperatures. A second characteristic of the acclimatized individual is the ability to secrete a more dilute sweat. This operates to permit an increased rate of sweating without increasing the drain on the salt reserve of the body. Thus it is important to restrict activity during the first few days in the desert, moreover, more salt may be required than later when acclimatization is complete.

2. PROCEDURE: Water intake was measured by the use of calibrated cups. All the urine voided by the subjects of the study was collected in individual containers and taken to the field laboratory for measurement of volume, specific gravity and chloride content. The men were weighed at frequent intervals (at least every 24 hours). The evaporative loss (designated net fluid loss in the following discussion) per day was calculated by subtracting the volume of urine voided from the total intake of fluid and adding or subtracting the weight change, depending on whether weight was lost or gained.

APPENDIX
(cont'd)

Group 1 was composed of several medium tank crews in a divisional encampment. This group of ten men were doing little or no driving at the time but were receiving gunnery instruction and were, therefore, less active than the next group that was studied. The diet was the standard modified field ration.

Group 2 consisted of 37 men of a light tank company who were engaged in maneuvers. They were on K-2 Ration through the 4 days of the study. This main group was subdivided into one group of 22 men who were allowed unlimited water, and another group of 15 men who were restricted to 4 liters* (4.2 quarts) per man per day. The restricted group was started on a water allowance of 2 quarts per man per day, but it was necessary to increase the allowance to 4 quarts before the end of the first day at which time a number of the men were in considerable discomfort. All men had access to salt tablets but these were almost never taken. Accordingly, the subjects of these tests can be considered to have received no salt other than that taken with food.

Group 3 was composed of members of the laboratory. They were on modified field ration most of the time. The period of study for each group is indicated on Chart 1.

3. RESULTS:

a. Air Temperature and Humidity. The average maximum temperature for the period of the study was 104°F. (See Chart 1) with maximum of 111°F. This represents mild desert conditions. The water and salt requirements found must therefore be considered minimum requirements. The highest air temperature recorded in a tank was 126°F. This was measured with the tank buttoned up and the engine dead at the end of 2½ hour run. The air temperature inside tanks rarely exceeded outside air temperature by more than a few degrees while the tanks were in motion. The humidity was consistently low (Chart 1); this and the constant breeze made for immediate evaporation of perspiration.

b. Total Water Intake. The average daily water consumption (Table 1) of both group 1 and group 2a (K-2) was about 5400 (5.7 quarts) ml. Under identical circumstances of activity and temperature about 1 quart more will be needed when on the K-2 Ration, since about that amount of water is provided by the field ration itself. Group 2b used slightly less than the water allotment of 4000 ml. Water intake for group 3 averaged about 4500 ml., somewhat less than the field units, as a result of less activity and exposure to heat.

In both groups 1 and 2a, some water intakes reached much higher levels, up to 12,000 and nearly 8,000 ml. respectively; these levels, amounting to more than 3 and 2 gallons, indicate that in certain instances water requirements may be considerable even at moderate desert temperatures.

*1 liter = 1000 ml. = 1.06 qts.

c. Net Fluid Loss. The net fluid loss, as mentioned, corresponds approximately to the sweat output; this quantity plus an additional amount to provide for adequate urine formation (500 to 700 ml. per day) represents the minimum water need for a particular amount of work and heat exposure. Stated in another way, reduction of water allowance to levels below the net fluid loss (plus about 500 to 700 ml. for urine) will result in dehydration. This will be associated with physical deterioration and fatigue. This was demonstrated by the reduction in water ration to group 2b (See Table I). The histograms in Chart 2 show the distribution of daily rates of sweating for groups 2a and 2b.

d. Net Fluid Loss and Task. In chart 3 the average net fluid loss per day (average for 3 days) of various crew members is shown. There is little indication that any particular crew members require unusual water allotments. There is, however, a tendency for the radio operator to manifest a slightly lower net fluid loss than the commander or driver.

e. Chloride Excretion. In all groups studied, safe levels of excretion (Table I) were maintained (excretion of less than 2 or 3 gms. sodium chloride per day suggests inadequate intake), indicating that no supplement of salt was needed under these conditions. This does not mean, however, that added salt would not be needed in the period of acclimatization or under more severe conditions of activity or high temperatures when losses in sweat are greater.

In the group receiving K-2 Ration (which contains about 16 gms. of salt) approximately 8 gms./day were lost in sweat. This corresponds to a concentration of about 0.2% sodium chloride in the sweat.

Mild nausea after taking salt tablets was reported fairly frequently by the men. This occurred shortly after taking the salt tablets and was probably a local gastric reaction. For this reason and because of carelessness salt tablets were rarely taken. It is probable that for moderate increases in salt requirement the problem may be satisfactorily solved by increased salting of the food. However, for high rates of sweating with water intakes of 10 or more liters (2½ to 3 qts.) a day (not unusual during severe desert conditions) it will be necessary to add salt to the drinking water. A concentration of 0.1% should be used.

f. Thirst. There was no general or consistent opinion among men questioned as to the value of thirst quenching devices such as chewing gum or fruit drops. Some individuals found one or the other effective in allaying the sensations of thirst; in other instances it was believed that they were of no advantage or actually increased thirst.

APPENDIX
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g. Pattern of Drinking. It was found that water consumption was substantially the same whether water was taken only at meal times or taken when thirsty. Those who delayed drinking until meal time experienced considerable discomfort without any apparent advantage in water economy or physical well-being. Drinking in small amounts when thirsty would seem to be the ideal practice. This would avoid the danger of cramps occurring as a result of drinking large amounts of water (especially when cold) at one time.

T A B L E I

GROUP		Number in Group	Initial Weight kgm.	Weight Change kg./day	Fluid Intake ml./day	Output (urine volume) ml./day	Net Fluid Loss (Intake - Output ± Wgt. Change) ml.or gms./day	Chloride Excretion gms. NaCl/day
1	Average	10	75.31	- 539.9	5486.9	1291.8	4570.8	8.55
	Range		67.3 - 87.5	- 2200 to + 610	1400 - 12,150	397 - 2955	2115 - 11,135	1.38 - 18.6
2a	Average	22	70.53	- 195.0	5113.7	866.7	4518.2	8.93
	Range		58.9 - 84.9	- 1290 to +1020	2950 - 7850	300 - 1770	3333 - 5677	3.00 - 17.0
2b	Average	15	70.61	- 333.0	3930.0	872.9	3382.3	8.99
	Range		55.6 - 83.2	- 1833 to +754	2950 - 4000	513 - 1990	2213 - 4207	5.18 - 16.0
3	Average	4	83.50	- 90.9	4481.9	1003.9	3626.8	7.63
	Range		65.0 - 91.0	- 1950 to +1400	2910 - 7030	470 - 2550	1800 - 5860	1.50 - 17.4

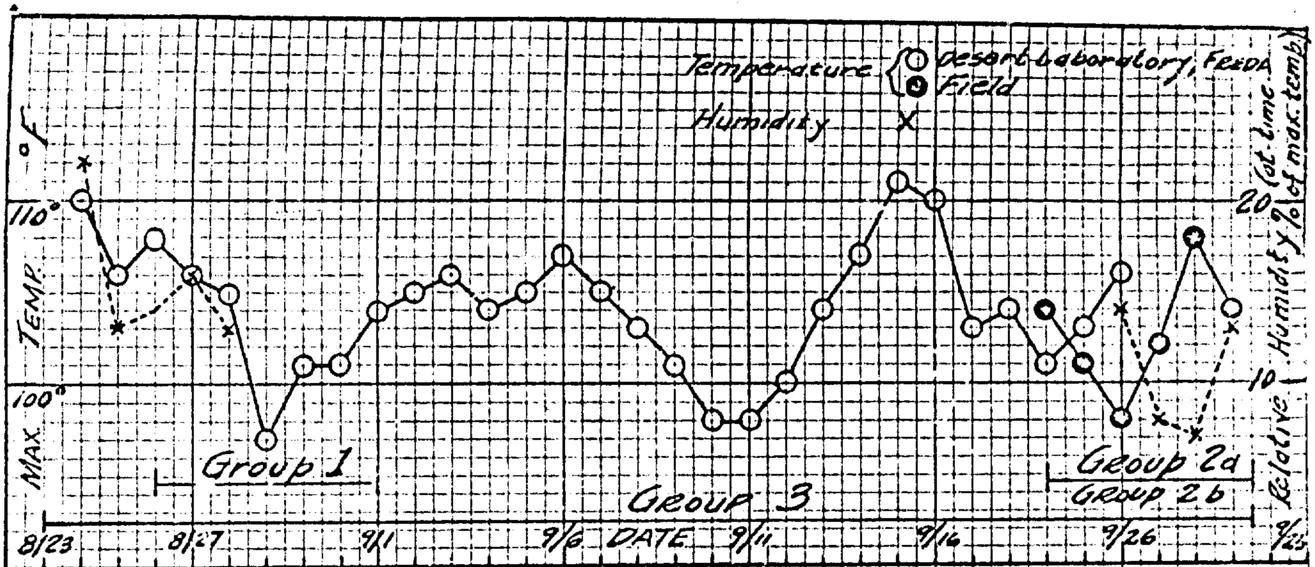

CHART-1

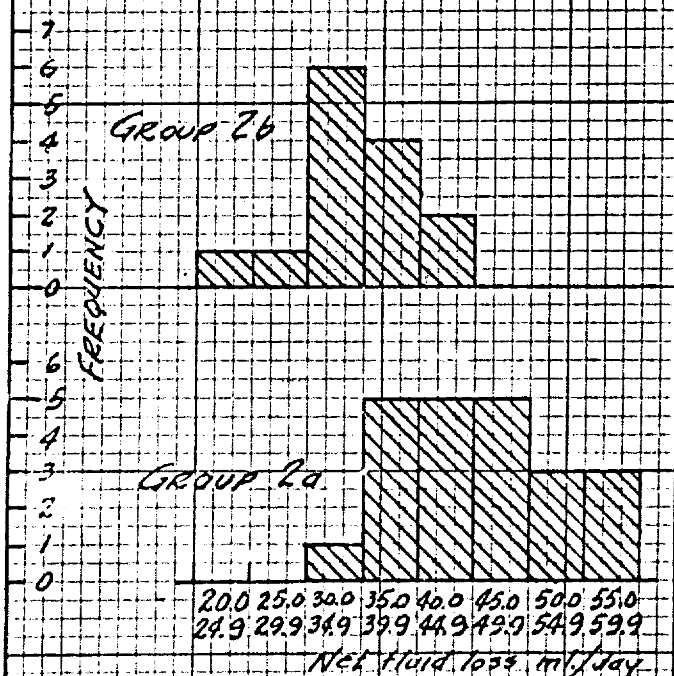

CHART-2

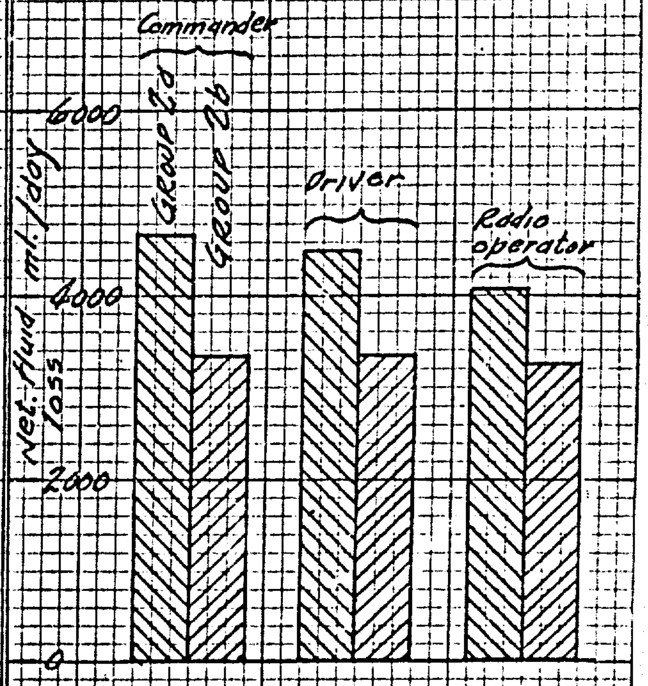

CHART-3